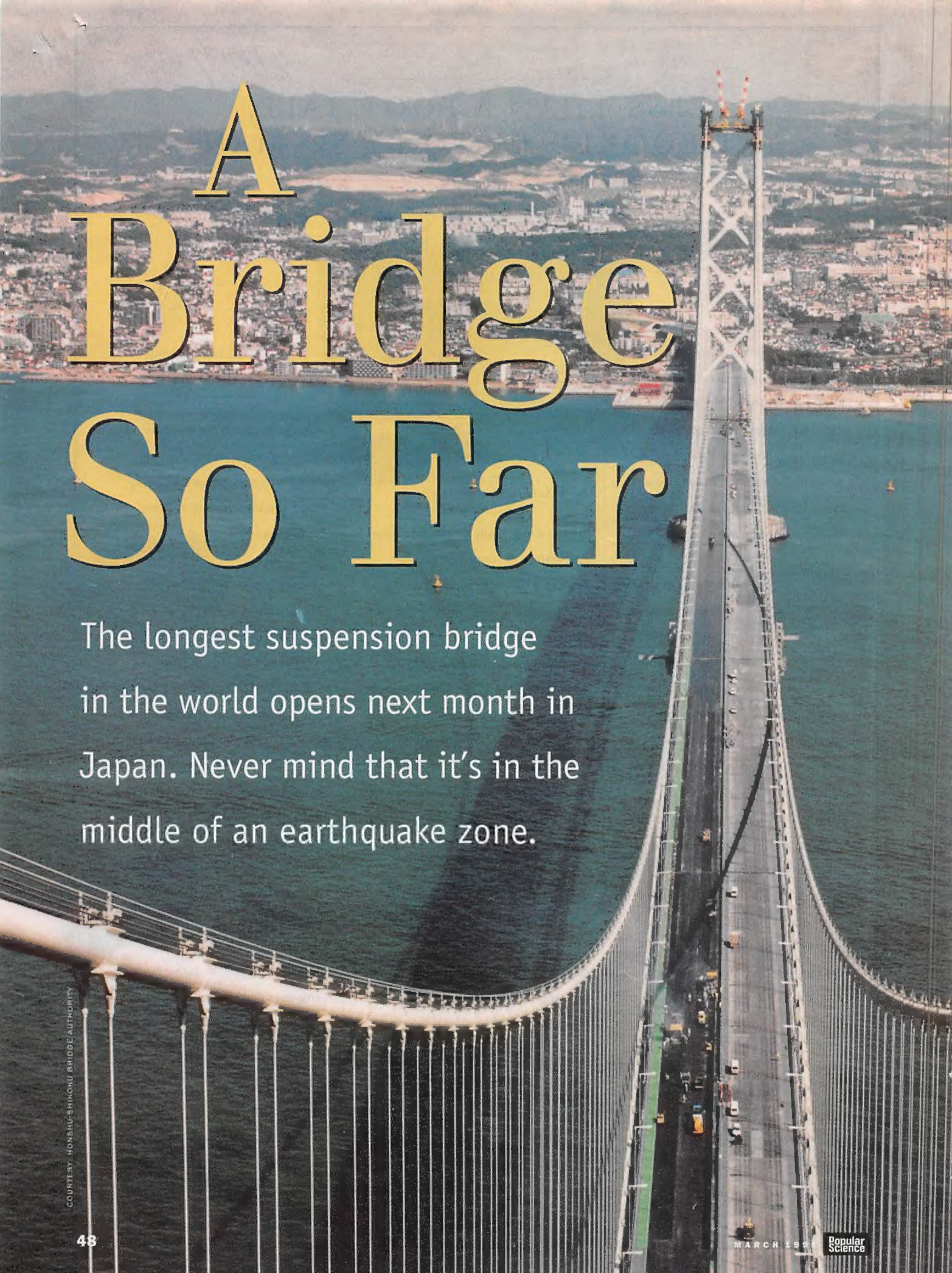
A Bridge So Far

The longest suspension bridge in the world opens next month in Japan. Never mind that it's in the middle of an earthquake zone.



COURTESY: HONSHU-SHIKOKU BRIDGE AUTHORITY

Bridges

LESS THAN A FOOT TALL, YET LOOKED UP TO BY SO MANY.

The Bose Acoustic Wave® music system.

The Bose® Acoustic Wave® music system is no bigger than a briefcase. Yet the sound it produces has commanded the respect of more than a few members of the audio press, not to mention thousands of music lovers. Once you hear it, we think you'll know why.

The system is the result of a 14-year effort by Bose to produce rich, natural, high-fidelity sound from a simple, compact unit. And at its core is a unique speaker technology: the acoustic waveguide, which won the prestigious "Invention of the Year" award. This patented, seven-foot waveguide speaker gives instruments and voices added clarity, makes subtle nuances come alive, and creates a full, rich bass.

"...One sexy unit that delivers a very big sound..." Spin

We believe the result is simply the most lifelike sound reproduction available in a unit this size. Sound that lets you hear your favorite music the way it was really *meant* to be heard. And with recent improvements, the system sounds more lifelike than ever—producing even richer, fuller, and clearer sound.

The system includes a compact disc player, an AM/FM radio, built-in speakers, and a convenient, credit card-sized remote control. All in one sleek, compact unit measuring just 10.5″H × 18″W × 6.5″D. And because it's so easily transportable, you can now enjoy full, high-fidelity sound almost anywhere.

"...Possibly the best-reproduced sound many people have ever heard..." Stereo Review

Unwind with rich Bose sound as you relax in your living room. Take the system out on the porch, plug it in, and invite some friends over. Or bring it to the office and enjoy the same component-quality sound you love hearing at home.

The Acoustic Wave® music system is available directly from Bose. So call 1-800-898-BOSE, ext. A2766, now to receive our complimentary information kit. And find out how you can try the system out in your home. If you aren't completely satisfied, simply return it for a full refund of the purchase price.

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DRIVE ACROSS THE world's longest suspension bridge and you'll be tempted to check the gas gauge to be sure you have enough fuel to get from one side to the other. You might also wonder about the wisdom of building Japan's grandest bridge in the middle of an earthquake zone. That may seem like a bad idea, but the bridge's construction has been a decades-old national dream—first proposed in the 1930s—that could only now be fulfilled thanks to today's technological know-how. When it opens on April 5, the Akashi Kaikyo Bridge will be the final link in a chain of spans that connects Japan's four main islands. Travelers will be able to transverse the country via a bridge network that already includes three of the longest suspension bridges in the world.

Everyone knew—or so they thought—that the nearest seismic fault was 90 miles away from the bridge site. So engineers from the Honshu-Shikoku Bridge Authority, formed in 1970, took the necessary precautions, designing the bridge to withstand an earthquake that would measure 8.5 on the Richter scale. Work began in May 1988 on the bridge, which ultimately would measure 12,828 feet, or 2.43 miles, in length. The center span alone is 6,529 feet, or 1.25 miles. The bridge links the main island of Honshu to the small island of Awaji, which, via another smaller bridge, is the gateway to Shikoku, home to 4 million people.

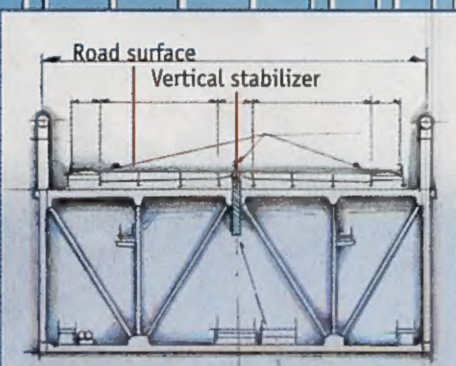
By Dennis Normile & Frank Vizard

By comparison, the longest suspension bridge in the United States (and number six in the world) is New York's 34-year-old Verrazano-Narrows Bridge at 4,260 feet. And the Akashi Kaikyo Bridge positively

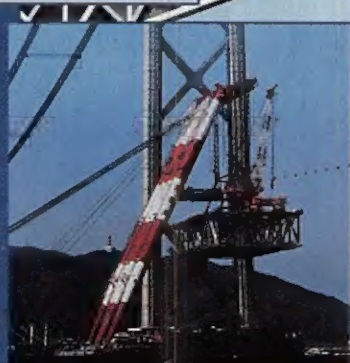
The Longest Bridge

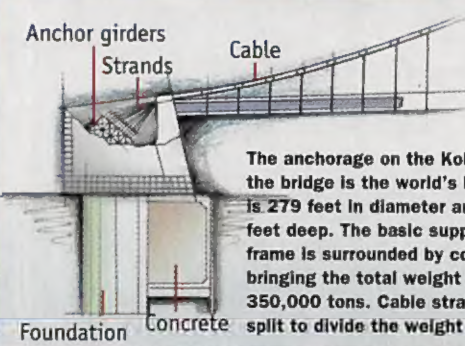
THE AKASHI KAIKYO BRIDGE in Japan is the world's longest suspension bridge, fulfilling a century-old dream of linking the island of Honshu to the island of Shikoku, both major population centers. In addition to the earthquake zone surrounding the bridge, the high winds associated with the region's typhoons were another obstacle to construction. Stresses on the bridge were simulated using a scale model built inside a wind tunnel. Building the bridge meant using new materials and techniques.

The Akashi Kaikyo Bridge has a span of 12,828 feet, or 2.43 miles. The center span alone is 6,529 feet, or 1.25 miles long. By comparison, the world's first suspension bridge, the Brooklyn Bridge, which was built in 1883, is 1,595 feet long.

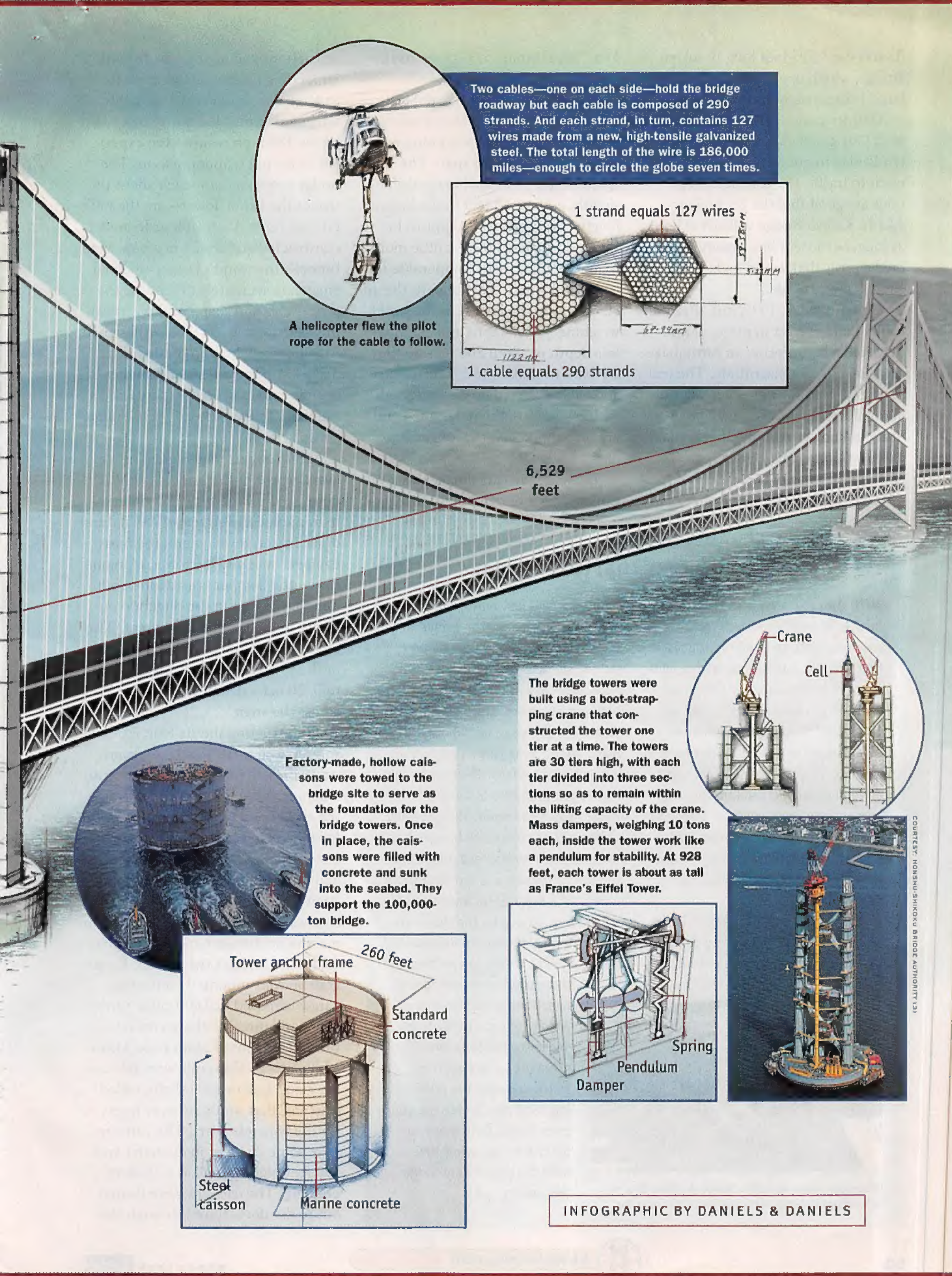


A floating crane raised the bridge's girders in sections. Even though the girders are considered strong but lightweight, 90,000 tons of steel were used in their construction. Special vertical stabilizers under the median strip of the deck reduce wind vibration by balancing the pressures on the upper and lower surfaces of the bridge.





The anchorage on the Kobe side of the bridge is the world's largest. It is 279 feet in diameter and is 207 feet deep. The basic supporting frame is surrounded by concrete, bringing the total weight to 350,000 tons. Cable strands are split to divide the weight equally.



Two cables—one on each side—hold the bridge roadway but each cable is composed of 290 strands. And each strand, in turn, contains 127 wires made from a new, high-tensile galvanized steel. The total length of the wire is 186,000 miles—enough to circle the globe seven times.

A helicopter flew the pilot rope for the cable to follow.

Factory-made, hollow caissons were towed to the bridge site to serve as the foundation for the bridge towers. Once in place, the caissons were filled with concrete and sunk into the seabed. They support the 100,000-ton bridge.

The bridge towers were built using a boot-strapping crane that constructed the tower one tier at a time. The towers are 30 tiers high, with each tier divided into three sections so as to remain within the lifting capacity of the crane. Mass dampers, weighing 10 tons each, inside the tower work like a pendulum for stability. At 928 feet, each tower is about as tall as France's Eiffel Tower.

COURTESY: HONSHU-SHIKOKU BRIDGE AUTHORITY (3)

INFOGRAPHIC BY DANIELS & DANIELS

dwarfs the 1,595-foot-long Brooklyn Bridge, which opened in 1883 as the largest suspension bridge of its time.

Despite periodic efforts by New York City dwellers to sell the Brooklyn Bridge to gullible visitors, it is still open to traffic 115 years later. The odds are good that the $3.3 billion Akashi Kaikyo Bridge will last at least as long, because it has already weathered a crisis that would make any Brooklynite shudder.

On January 17, 1995, just after the cables had been set in place, nature delivered a big surprise: an earthquake measuring 7.2 in magnitude. The real shock was that the epicenter was only about 2.5 miles away, along a previously unknown fault line that actually extended under the center span. The earthquake smashed the nearby city of Kobe ["A Wake-up Call from Kobe," Feb. '96], claiming 5,000 lives and destroying 100,000 buildings.

Remarkably, the bridge did little more than stretch a little—it was as if the earthquake drew nothing more than a yawn from the span. The southern pier and anchorage shifted slightly, adding 2.6 feet to the bridge's length. This meant the approaches to the bridge needed to be a little more than 4 feet higher to compensate for the added length. Fortunately, the anchorages are the largest in the world, weighing 350,000 tons and extending to a depth of about 208 feet, so they are hard to shake loose. The towers and cable suffered no damage, and within a month, the redesigned girders accommodated the longer length of the bridge.

In a way, the earthquake was a fitting test for a bridge built under tight restrictions and an eye cast toward impending disaster. In addition to earthquakes, engineers also had to safeguard against the buffeting caused by the 180-mph winds often experienced during typhoon season. The bridge towers alone—each about the size of the Eiffel Tower—are the tallest ever built. A 1-to-100 scale model constructed and tested in a new wind tunnel—the world's largest—helped engineers accurately determine the proper size and shape of the vertical fins called stabilizers that are designed to minimize vibration of the bridge deck. From these tests and studies of seismic activities, engineers devised a number of new approaches to bridge construction.

While engineers designed nearly every aspect of the bridge—right down to the wind-resistant girders—to minimize the effects of any natural disaster, one key element, the mass dampers built into the tower, is unique. Inside the damper is a 10-ton pendulum that swings in the direction opposite to the tower's movement. This effectively dampens the movement of the tower, keeping it stable. All told, 20 mass dampers are in place across the span.

Constructing the six-lane 116-foot-wide Akashi Strait ("kaikyo" means strait) presented a challenge, because shipping still needed to pass through the strait connecting Osaka Bay and Japan's Inland Sea. This is why the center span is so long—the towers had to be built on both sides of the strait's navigable channel. The first step was to prepare the seabed for the massive anchorages and for the piers under the bridge's two towers. Large grab-buckets mounted on floating barges removed 720,000 cubic yards of silt and muck so these concrete foundations could sit on rock. Meanwhile, nearby shipyards were fabricating giant, hollow steel shells, called caissons, that would serve as forms for the concrete piers. The caissons were some 262 feet in diameter and 230 feet high—as tall as a 25-story building. The caissons were floated out of dry dock, towed through the

Smart Bridges That Last Longer

WITH AN estimated 230,000 U.S. bridges in need of serious repair, a new emphasis on building bridges that will last a long time with a minimum of maintenance is emerging.

Perhaps the smartest bridge in the United States is the Winooski River Bridge in Waterbury, Vermont. Engineers from the nearby University of Vermont are embedding fiber-optic sensors into the steel truss bridge to check its health. The sensors are linked to a computer that monitors the bridge for cracks, strain, and road-salt corrosion.

On the flip side of the coin is an effort to build bridges using composite materials that require virtually no maintenance—just build 'em and forget 'em. A new 36-ton bridge in Butler County, Ohio, is one of the earliest successes. The Tech 21 bridge is made of lightweight, corrosion-resistant polymers. State officials expect the bridge to last about 150 years, about three times longer than conventional bridges. The new bridge cost about $100,000 to build—roughly twice the norm. The generally higher cost of composite bridges has hindered their widespread adoption.

Low maintenance is also the prime benefit of a new denser and stronger concrete developed by the University of Cincinnati. This high-performance concrete (HPC) allows longer beams to be used, eliminating the need for connecting piers, which collect debris. The denser concrete is more resistant to salt erosion, which corrodes the reinforcing steel bars inside the concrete beam. Ohio plans to build a bridge using HPC near the city of Cambridge this spring.—*F.V.*

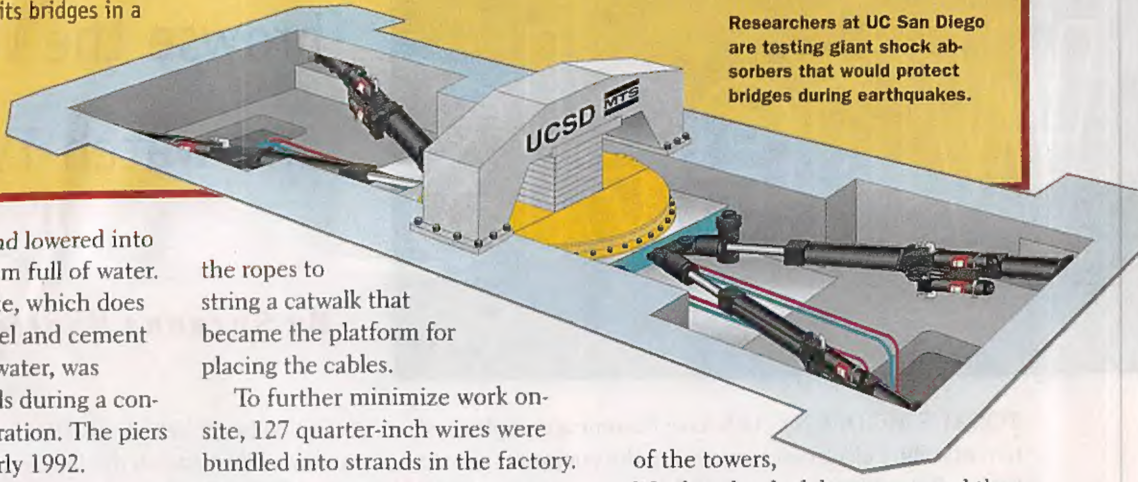
Fiber-optic sensors in the Winooski River Bridge in Vermont detect cracks, strain, and corrosion.

Shock Absorbers for California Bridges

EVER SINCE the 1989 Loma Prieta earthquake in which a 50-foot section of the Bay Bridge between Oakland and San Francisco collapsed, California has been studying ways to make the state's bridges quake-proof. While it now seems likely that the Bay Bridge, which opened in 1936, will be replaced in a project scheduled to begin in 2000, the state is actually retrofitting most of its bridges in a $2.6 billion project.

Among the bigger undertakings is the retrofitting of the 29-year-old San Diego-Coronado Bridge. Strengthening 11 girder hinge sections will limit the bridge's movement during an earthquake. Adding metal stifffeners will also restrict movement. The last major tremor in the area of the bridge was the 1971 San Fernando earthquake.

California is also testing a new technology at the University of California, San Diego. Longer span bridges like the San Diego-Coronado Bridge would be fitted with huge flexible isolation bearings and dampers that crews would place between the superstructure and the supporting columns. These devices would essentially act like shock absorbers to mitigate the effects of a quake.—*F.V.*



Researchers at UC San Diego are testing giant shock absorbers that would protect bridges during earthquakes.

Inland Sea by tugs, and lowered into place by pumping them full of water. Then, marine concrete, which does not separate into gravel and cement when dumped underwater, was pumped into the shells during a continuous three-day operation. The piers were completed in early 1992.

To erect the 928-foot towers, contractors welded the steel plates of the tower legs to form hollow box-like sections called cells, barged them to the site, then stacked and welded them like building blocks. Cell size was limited by the 160-ton capacity of the climbing crane, so each tower was split into 30 tiers roughly 31 feet high. Each tier was made up of three cells, for a total of 180 cells in each tower. The cell sections were constructed in on-shore factories, reducing dangerous on-site work, improving efficiency, and resulting in greater accuracy when the time came to fit the pieces of the bridge together.

The towers were ready for cable to be strung between them in November 1993. The pilot ropes—the first, temporary cables strung from one anchorage over the towers to the other anchorage—are typically pulled across by barge. But since the bridge crosses a shipping lane used by as many as 1,400 vessels each day, a helicopter replaced the barge. After flying the pilot ropes across the straits, workers used the ropes to string a catwalk that became the platform for placing the cables.

To further minimize work onsite, 127 quarter-inch wires were bundled into strands in the factory. These wires were made of a new high-strength steel that is 12.5 percent stronger than in previous bridges. This allowed engineers to use two main cables instead of the four envisioned in preliminary designs, reducing the weight of the bridge and speeding up construction. The strands were wound on spools, hauled to the site, and then pulled from anchorage to anchorage. Each 3.7-foot-diameter cable is made up of 290 strands.

Contractors began erecting the redesigned truss in June 1995, using a 4,000-ton-capacity floating crane to lift into position preassembled sections that were the full width of the bridge, 46 feet deep, and the length of a football field. The contractors would have liked to use this method for the entire truss, but floating cranes would have interfered with navigation. Instead, only the sections adjacent to the towers and anchorages were set this way. For the rest, assembled truss panels averaging 46 feet square were barged to the base of the towers, lifted to the deck by cranes, and then rolled on carts to the working face, where traveling cranes slung them into position.

That sounds easier than it was. Prior to their completion, the trusses were very susceptible to buffeting winds. Work was halted when the gusts topped 36 mph, so construction moved at about 60 percent of normal pace. Despite the winds and the earthquake, work proceeded rather smoothly and the final truss bolt was tightened on schedule in September 1996. Painting, paving, and other miscellaneous work has also proceeded as planned. And all signals are go for the April 5 grand opening.

Longer suspension bridges are being proposed to connect Sicily and Italy, and to cross the Straits of Gibraltar. But neither these nor other proposed long-suspension spans seem likely to be constructed in the near future. This will likely leave the Akashi Kaikyo Bridge holding the crown as the world's longest suspension bridge for years to come. ◆

WIRED Wheels

A new "network vehicle" lets you check e-mail while driving, as your passengers browse the Web and watch TV.

By Suzanne Kantra Kirschner

TODAY'S MODERN CARS have become a complex system of rolling electronics, mirroring the computer age we live in. But aside from your cellular phone, your car rarely communicates with the outside world—or with you. The era of automotive solitude is coming to a close, however.

Delco Electronics (a unit of GM), IBM, Netscape, and Sun have teamed up to create the world's best-connected car, dubbed the Network Vehicle. This demonstration car meshes the usual auto electronics with a host of audio, video, computer, phone, satellite, and GPS devices, all linked by a looping network within the car. You can't buy a Network Vehicle yet, but Delco and IBM predict you'll be able to purchase a car like it in three to seven years.

In the meantime, the Network Vehicle provides plenty of technological teasers. Once inside, a voice-recognition system lets you talk to your car, and allows your car to talk back to you. A satellite dish embedded in the car's roof and LCD screens built into the car seats provide both TV programs and Internet access. A cellular phone and a head-up display system let you communicate while driving. Your vehicle's own Web site and GPS system give you new control, navigational, and emergency options. And most components can work together with interesting results.

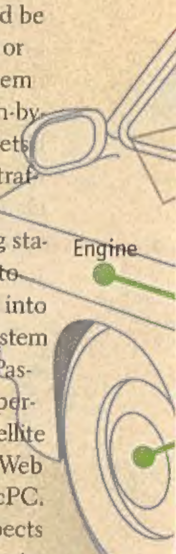
When something goes wrong in your Network Vehicle, for instance, it warns you with an audible message. You can then call a service center for help; the center can do a diagnostic check remotely and access your car's maintenance log. And if you get stuck or lost, they can dispatch help to your exact location by reading your GPS signals, or provide directions to the nearest gas station or hotel.

The Network Vehicle also lets you keep in touch while you drive. The head-up display alerts you to incoming calls or e-mail messages by projecting icons that appear to be visible beyond the car's hood—where your eyes would be anyway. You can vocalize your wish to answer the call or have the e-mail read to you aloud. The navigation system is also linked into the head-up display, projecting turn-by-turn instructions. And the voice recognition system lets you dial the phone, select a radio station, or retrieve traffic updates, stock quotes, and news via the Internet.

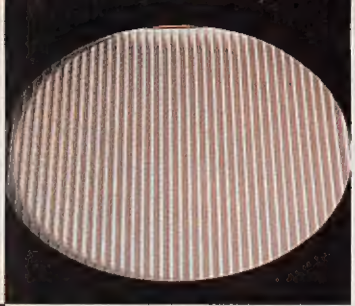
You can customize your drive time, too. A docking station for IBM's WorkPad handheld computer (similar to 3Com's Pilot) enables you to download your schedule into the car for better route planning. And the navigation system can keep a mileage log for easier expense reporting. Passengers won't get bored, either. They can watch pay-per-view movies and standard TV fare via the DirecTV satellite service, or use the touch-screen color LCDs to surf the Web using its companion high-speed Internet service, DirecPC.

Some of the Network Vehicle's most tantalizing aspects stem from the fact that it's essentially a mobile Internet server with its own Web address. Amenities such as radio presets, seat position, and cellular phone numbers can be programmed while sitting at a computer. More importantly, perhaps, you can use the Internet connection to remotely lock your car, turn off the lights, or even shut off the engine if the vehicle's been stolen.

The Network Vehicle won't be alone on the high-tech highways. Clarion and Intel have less elaborate computer car systems that should be available later this year.



This touchscreen LCD lets you control nearly all vehicle systems and services from five categories: entertainment, navigation, office, Web site, and information. Depending on the mode, the console becomes a cellular phone, a CD player, a navigation system (shown), an Internet radio, or a climate-control panel, among others.

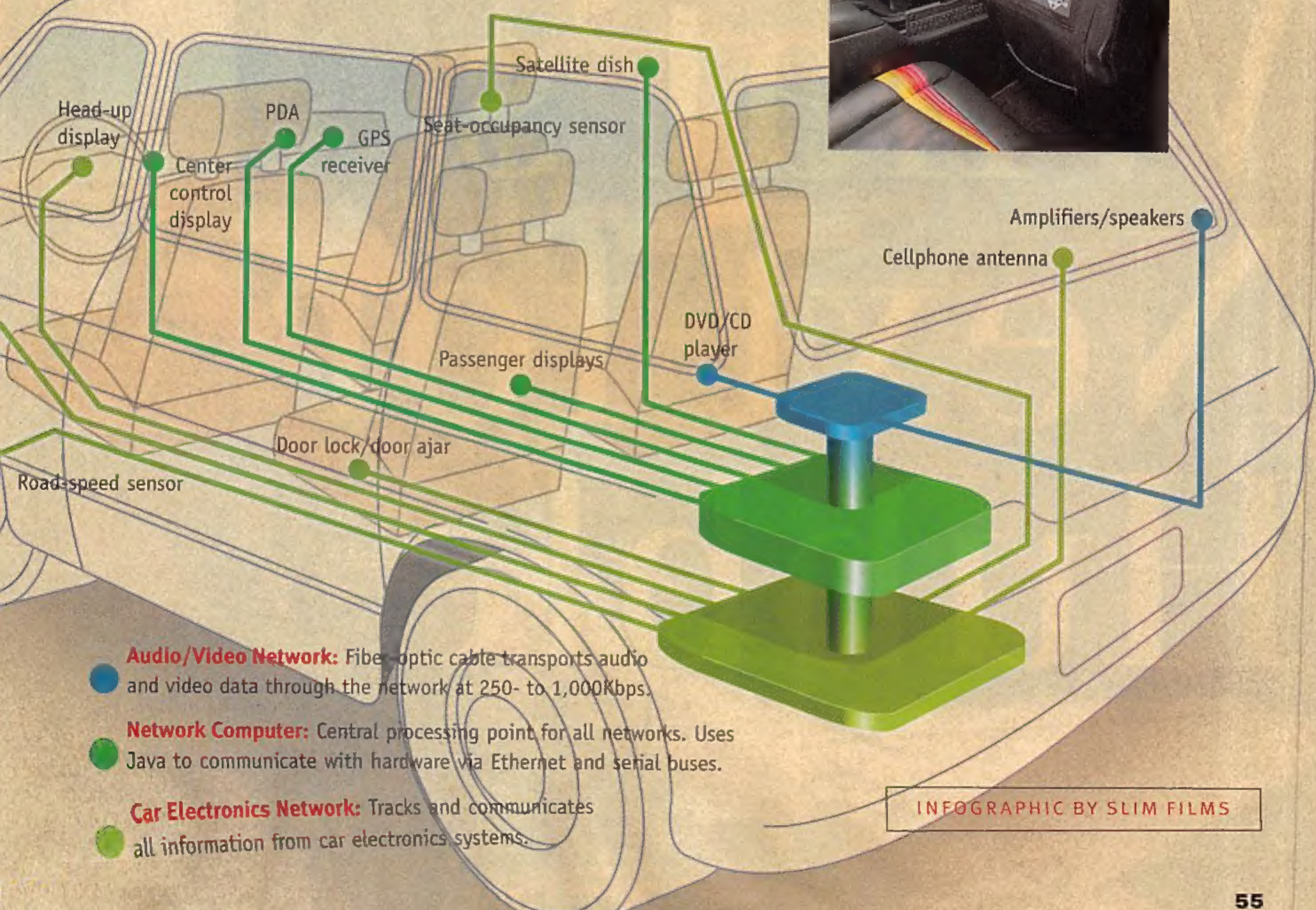


JIM FRENAK (3)

Protruding a scant 2 to 3 inches from the roof of the vehicle, the flat onboard satellite dish can pick up a signal from any angle. You can connect to the Internet at high speeds via the DirecPC satellite data service, with the uplink provided by a radio-frequency modem. Movies and other audio and video programming are beamed in from DirecTV satellites.

Touchscreens to the side of the passenger displays enable you to quickly navigate through services. You can type on a wireless keyboard.

From any passenger display, you can access a host of entertainment and information services, including DVD movies, audio-on-demand from DirecTV, and Web sites.



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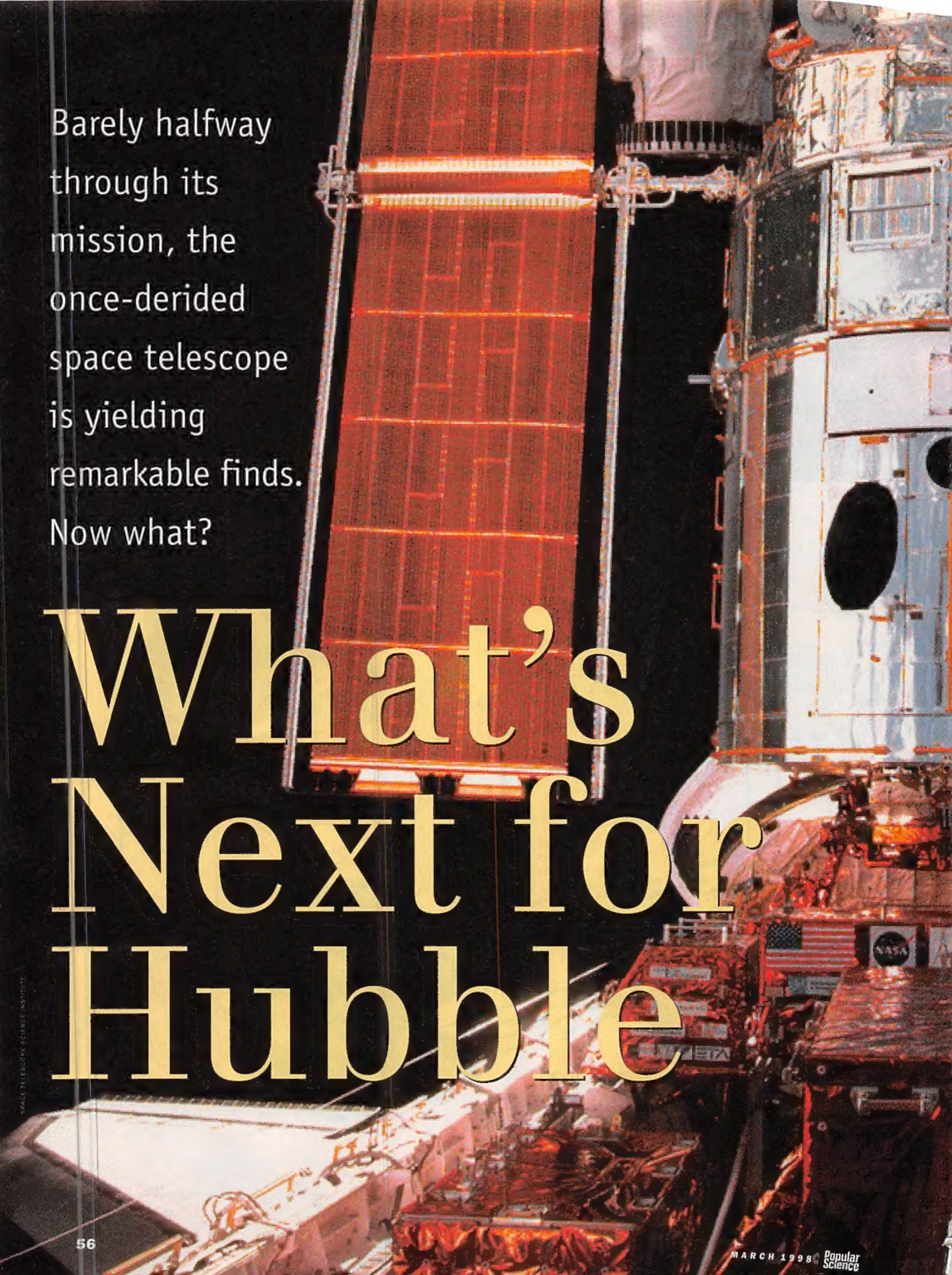


What's Next for Hubble

Barely halfway through its mission, the once-derided space telescope is yielding remarkable finds. Now what?

SPACE TELESCOPE SCIENCE INSTITUTE

Science Renewal

DURING A FEBRUARY 1997 servicing mission, the bus-size Hubble Space Telescope was berthed aboard the space shuttle so spacewalking astronauts could install new instruments, giving the telescope new science capabilities.

By Mariette DiChristina

WHIZZING THROUGH its orbit at 17,500 mph amidst the silence of space, perhaps only the Hubble Space Telescope has been unaware of its stunning transformation from astronomy boondoggle to boon during its eight-year life.

Once ridiculed as a nearsighted "techno-turkey," the $3 billion telescope is today a sought-after tool for astronomers that is producing one important find after another. Named after Edwin Hubble, who in 1929 discovered the expansion of the universe, the telescope is making remarkable progress toward its goals: to peer to the edges of the cosmos and help answer some of humanity's loftiest questions. Among them: How old is the universe? How big? How has it evolved?

"We're damn lucky—we're blessed—to have that sucker up there," exults Robert Williams, the director of the Space Telescope Science Institute in Baltimore. In a vote of confidence, the telescope's planned 15-year mission was recently extended at least five years more, to 2010. As the Hubble continues to peek at the edges of the visible universe, it's time to take a look at where the telescope has been, what it has accomplished, and what lies ahead.

The telescope's story begins in 1946, when Princeton astronomer Lyman Spitzer proposed an American space telescope. After Congress authorized the program in 1977, however, it was beset by delays, snafus, and cost overruns. When the 94.5-inch (2.4-meter) primary mirror was completed in 1981—after five years of grinding and polishing—it cost $3 million more to make than was budgeted. And various glitches and the three-year shuttle-flight hiatus after the tragic loss of the Challenger in 1986 delayed the launch until April 24, 1990.

Exuberance over the telescope's successful "first light"—the first time it imaged a heavenly body—soon turned to anguish when the telescope was discovered to be nearsighted. The primary mirror had been ground ten-thousandths of an inch too flat at the edges. Making matters worse, the solar panels flexed every 90 minutes—each time the telescope crossed the line that separates night and day—causing view-blurring jitter. "To Hubble something" entered the vernacular as a way to describe a colossal foul-up, and critics even began to question the continued existence of NASA.

Three years later, a dramatic $250 million, 11-day repair tuned up the ailing telescope. Astronauts installed corrective optics ("eyeglasses"); less flexible solar arrays to stop the jitter; an upgraded camera for better images of star fields and planets; and more.

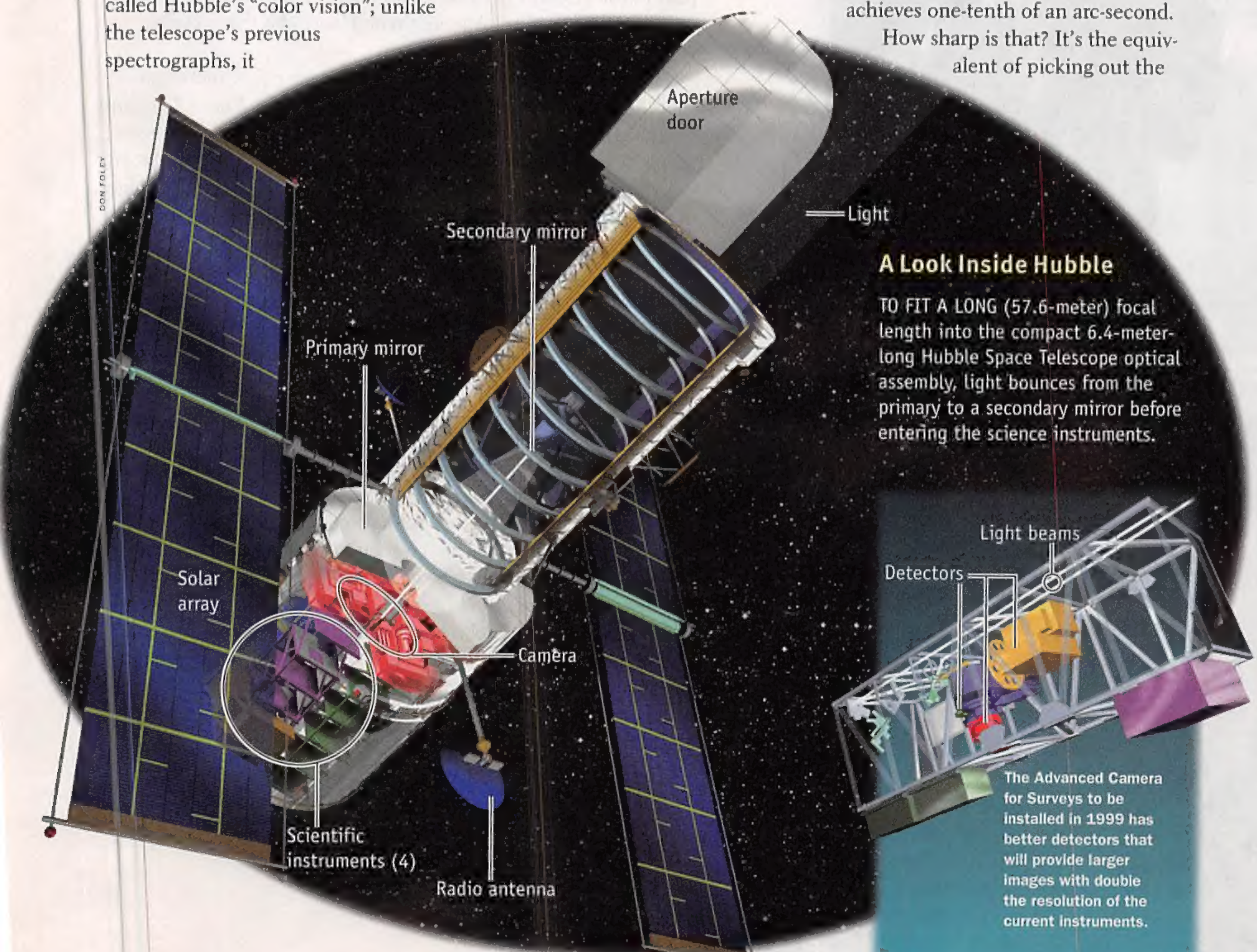
NASA followed up with a second, $350 million servicing mission in February 1997. Astronauts also installed two instruments new to the Hubble that increased the telescope's data-gathering power by a factor of ten. One is the Near-Infrared Camera and Multi-Object Spectrometer, which extended the telescope's capability into the infrared light wavelengths, longer than the red light humans can see in the electromagnetic spectrum. The second, the Space Telescope Imaging Spectrograph, has been called Hubble's "color vision"; unlike the telescope's previous spectrographs, it can look at many—up to 512—different areas or objects in space at once, to learn clues about their composition, speed, and temperature.

To upgrade the storage capacity to handle this new data, astronauts replaced a tape data recorder with a solid-state version. And in contrast to earlier technologies, the new instruments have built-in intelligence so they can work together, and work with another camera already aboard the telescope. Imaging simultaneously in different wavelengths gives astronomers a better understanding of an object.

With the Hubble's new instruments, "It'll look in the infrared and see a different universe. To look 10 billion years ago, you have to look at the infrared," says Williams. And in the infrared is where the Next Generation Space Telescope, the successor to the Hubble, will specialize. (See "The Space Telescope of the New Millennium," page 60.) "Looking at the stuff from billions of years ago—that's the stuff out of which we were formed," he says. "Astronomy seeks answers to life's most profound questions, such as: Where did we come from? Where are we headed?"

The Hubble is poised to help answer such questions from its vantage point in orbit above Earth. Peering through the haze of our planet's atmosphere, ground-based telescopes can resolve an image to about one arc-second (equal to $1/3{,}600$ of one degree in the 360-degree "pie" that makes up the sky). The Hubble achieves one-tenth of an arc-second.

How sharp is that? It's the equivalent of picking out the



A Look Inside Hubble

TO FIT A LONG (57.6-meter) focal length into the compact 6.4-meter-long Hubble Space Telescope optical assembly, light bounces from the primary to a secondary mirror before entering the science instruments.

The Advanced Camera for Surveys to be installed in 1999 has better detectors that will provide larger images with double the resolution of the current instruments.

Links to the best Hubble sites www.popsci.com

individual lights of two fireflies sitting atop the palms of a person with outstretched arms in Tokyo, from a vantage point in New York.

"I believe the great legacy of the Hubble will be the clear view it gives us of the distant universe," says Williams. "A century or two from now, that will be the essential thing we got from the Hubble."

Looking deep into space, the Hubble is helping astronomers learn about the universe's expansion rate, and what may be its eventual fate. Researchers are zeroing in on the Hubble constant, a critical mathematical figure devised by Edwin Hubble in 1929 that will reveal how fast the universe is expanding, by using the telescope to locate special stars called Cepheid variables, as well as distant supernovae. These bodies can be used as yardsticks to measure the vastness of space. If there is enough mass, the so-called critical mass, and expansion slows over time, a theory goes, eventually the universe could recollapse for another Big Bang. The universe would then begin again.

According to Williams, however, telescope data indicates that the expansion is not really slowing down. "The universe may coast to infinity," he says. As it continues to expand, stars would burn out over the eons, and the universe would come to a brutally cold, black end. That finding is surprising to many astronomers, who favor the idea that the universe would continue in some fashion.

In other Hubble achievements, the telescope has been able to detect the chemical composition and nature of stellar objects in nearby galaxies. The telescope also has a unique ability to view the universe in ultraviolet, which is not possible with ground-based telescopes because such light is largely blocked by Earth's atmosphere. Some hot, young stars are more visible in ultraviolet, for example.

Closer to home, the telescope probes our planetary neighborhood. Unlike single missions such as the famously successful Galileo probe of the planet Jupiter, the Hubble can study objects night after night. For example, it watched while the fragments of Comet Shoemaker-Levy 9 blasted the big planet, and imaged volcanoes on the Jovian moon Io.

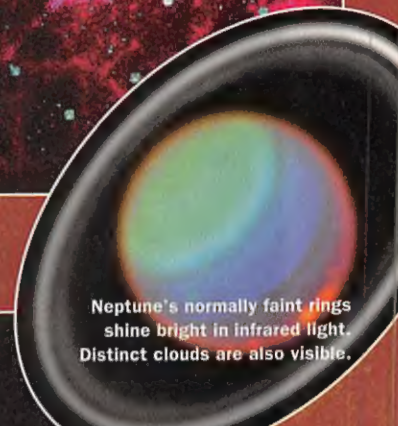
With these enhanced capabilities, is there anything the Hubble *can't* detect? "Extraterrestrial intelligence," snorts Williams. "That's one thing the Hubble will never find."

Kidding aside, Williams hopes that the Hubble's mission will be expanded to include a new kind of investigation. A few years back, the Hubble took a view, or survey, deep into space. Known as the Hubble Deep Field, this striking survey turned up more than 3,000 distant galaxies and helped determine how star formation in the universe has evolved over time. The equivalent of fishing expeditions, surveys could find as-yet-unsuspected phenomena. "I believe that is the most likely area in which the Hubble could revolutionize our view of the distant universe," says Williams.

One instrument ideally suited for what Williams envisions is the Advanced Camera for Surveys. The camera is slated to fly to the Hubble on its next servicing mission, scheduled to launch in December 1999. The camera, which will replace the 1970s-era Faint Object Camera, will have larger detectors, for a larger view of the sky. It also will offer twice the detail that is now possible with current instruments. The '99


The new near-infrared instrument peered through interstellar dust to find the Pistol Star, perhaps the most massive star ever.

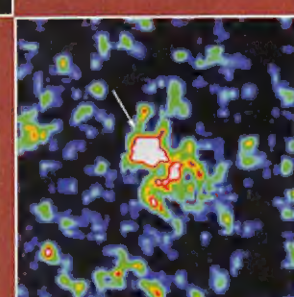
SPACE TELESCOPE SCIENCE INSTITUTE


Neptune's normally faint rings shine bright in infrared light. Distinct clouds are also visible.


The Wide-Field and Planetary Camera captured the rolling jet-like exhausts from a dying star.

Hubble Science

IN THE past year, the Hubble has churned out a gallery of finds, many with the help of two new instruments installed during the 1997 servicing mission.


The first optical counterpart of a gamma-ray burst and its potential host galaxy suggests a cosmic origin for these puzzling energy releases.


The new spectrograph reveals chemical components around supernova 1987A, including oxygen (single green ring) and nitrogen and hydrogen (triple orange rings).

More stunning shots taken by Hubble www.popsci.com

The Space Telescope of the New Millennium

THE HUBBLE SPACE TELESCOPE will orbit Earth for at least another dozen years, but plans are already on the drawing board for its successor, which will be called the Next Generation Space Telescope.

The NGST, as it is known, will pick up where the Hubble leaves off in the search for knowledge about the early evolution of the universe, when it was between 100 million and 1 billion years old. "The NGST has as a primary science goal the study of the very early universe," says Harlan Thronson, deputy program scientist for the Hubble at NASA headquarters in Washington, D.C. "The Hubble can look to objects back to 10 to 20 percent of the current age of the universe," says Thronson. "The NGST will look back to a fraction of a percent. It should see galaxies as they form."

While the Hubble specializes in examining the cosmos in the shorter wavelengths of ultraviolet and visible light, the NGST will delve into the universe at the longer infrared area of the electromagnetic spectrum. Because galaxies are moving away from ours as the universe expands, their light is shifted to the longer red wavelengths—it reaches Earth at infrared wavelengths.

To do this, the NGST will be larger than the Hubble, which has a 2.4-meter primary mirror. The new telescope will have a 6- or 8-meter mirror. It will have a larger aperture—two to four times that of the Hubble, for four to 16 times greater collecting area. "Because the NGST is working at longer wavelengths, it will have an approximately similar clarity of view as the Hubble," adds Thronson.

There will be other differences as well. The NGST will not circle Earth, but occupy a stable orbit between our planet and the sun about 1.5 million kilometers distant, past the moon. And while the $3 billion Hubble embodies the old "big science" thinking, the NGST has been conceived under NASA's current goal of "faster, better, cheaper" missions. The entire development of the telescope is targeted for $500 million, with $400 million more expected over its planned 10-year lifetime.

"It's expensive to maintain the Hubble, and to make systems [for the telescope] that can be pulled out. It's expensive to train astronauts for servicing missions," says Thronson. "The downside [for the NGST], of course, is that if a catastrophic problem occurs, you would not be able to service it as with the Hubble."

Not orbiting Earth has advantages for science as well. "The NGST has to be very cold to work in those infrared wavelengths," says Thronson. Too much heat degrades the performance of the sensitive detectors, which will be cryogenically cooled. The NGST is expected to be 1,000 times more sensitive than any existing or planned ground or space telescope. "We don't want energy from the instruments [or Earth sources] to overwhelm the faint objects," adds Thronson.

There are four competing NGST designs, from Ball Aerospace & Technologies Corp. of Boulder, Colorado; Lockheed Martin Corp. of Bethesda, Maryland; TRW Space and Electronics Group of Redondo Beach, California; and Goddard Space Flight Center of Beltsville, Maryland. Three of the designs feature foldable parts, so the telescope could fit aboard an Atlas-class or other expendable launch rocket.

The decision about which design to pursue would likely be made around 2002, so construction could begin the following year, says Thronson. The NGST weight goal is 3,000 kilograms (compared with 11,000 for the Hubble), so creating its large, lightweight mirrors will require breakthrough materials advances. Some of the designs also borrow inspiration from military satellites, says Thronson.

Like the Hubble, the NGST may have international partners. In preliminary funding discussions, the European Space Agency, a 15 percent partner in the successful Hubble, has expressed interest in contributing to the NGST around that percentage. Canada is also considering joining the project, perhaps at the 5 percent level.

If all goes as planned, the NGST will launch in 2007. With the Hubble mission recently extended to 2010, two space telescopes could be plying the skies together for three years. "The two in tandem will be a real one-two punch," says Dave Leckrone of the Goddard Space Flight Center.—*M.D.*

One of four competing designs for the Next Generation Space Telescope, this concept by Ball Aerospace would use 32 segments to make up an 8-meter mirror. The sunshades and secondary mirror would fold to fit aboard a launch rocket.